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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

**MODELING THE PROJECT CAPACITY OF THE
SACRAMENTO DISTRICT ARMY CORPS OF
ENGINEERS**

by

Carl W. Koehlinger

June 2011

Thesis Advisor:

Scott Nestler

Second Reader:

W. Matthew Carlyle

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**MODELING THE PROJECT CAPACITY OF THE SACRAMENTO DISTRICT
ARMY CORPS OF ENGINEERS**

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Lieutenant Colonel, United States Army Reserve
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

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ABSTRACT

Each year the Sacramento District of the United States Army Corps of Engineers must submit an estimate of its available project capacity for input to the President's Budget request. Currently, the District estimates this amount based on past experience and regression analysis on limited data. We develop a project capacity and leveling model for the Sacramento District Office. We use historical data provided by the Sacramento District from 2009 to 2011 to build and test the mixed integer linear programming model. The model assists the District with estimating its capacity for additional work for budget submission. Results of the model show the effects of allowing projects to shift forward or back in time in the schedule and adding project work on employee utilization, contractor utilization, and leveling monthly project work. We recommend expanding the model with more detailed resource requirements for each project to identify for the Sacramento District where to allocate its scarce resources to achieve the best effects for total project portfolio management.

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LIST OF ACRONYMS AND ABBREVIATIONS

CPM	Critical Path Method
ERDC	Engineer Research and Development Center
FTE	Full Time Equivalent
FY	Fiscal Year
GAMS	General Algebraic Modeling System
GERT	Graphical Evaluation and Review Technique
HRM	Human Resources Management
MOE	Measure of Effectiveness
O&M	Operation and Maintenance
PB	President's Budget
PERT	Program Evaluation and Review Technique
Q-GERT	Queue Graphical Evaluation and Review Technique
R&D	Research and Development
SAM	Sacramento Allocation Model
USACE	United States Army Corps of Engineers

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EXECUTIVE SUMMARY

The Sacramento District office of the United States Army Corps of Engineers manages civil works, environmental, and military projects. Its customers are the Department of Defense, other federal agencies, and regional, state, and local governments and authorities.

Civil works projects, conducted in partnership with regional, state and local governments and authorities, usually require greater than \$10 million and last from ten to fifteen years. The majority of military projects cost less than \$1 million, and last less than one year. Environmental projects and larger military projects span the duration gap between civil works projects and small military projects. Civil works projects, environmental projects, and larger military projects are funded via request by the Army through the President's Budget (PB) process or as congressional inserts to the budget. This funding is spread over multiple years. About 35%–50% of the funding for civil works projects comes from partner organizations. The partner organizations are usually state and local agencies. In comparison, smaller military projects are often funded with installation or base commanders' operation and maintenance funds. This type of money usually expires at the end of each fiscal year. This means that these projects need to go from concept, through some level of design, to contract within a fiscal year.

Each year, the Sacramento District is asked to estimate its capacity for new work in the civil works area. This capacity is used for input into the federal budget process. Currently, it estimates this amount based on past experience and regression analysis on limited data. By estimating its total project management and design capacity and then subtracting the current budgeted project expenditures during the next fiscal year, it provides an estimate used as an input to the annual PB submission.

We develop a project capacity and leveling model for the Sacramento District office. We then use historical data provided by the Sacramento District from 2009 to 2011 to build and test the mixed integer linear programming model.

The inputs to the model are the monthly project budget amounts and the number of available employees by occupation, grade, and experience. The decision variables are the number of employees to assign to a project, the number of contractors to assign to a project, and how many months to shift a project earlier or later in the schedule. The objective function maximizes the value of the lowest total amount budgeted in any month within the time horizon of interest. This has the effect of reducing the variation of the total of all project budgets from month to month.

Penalties are subtracted for the percentage of the total budget contracted outside the desired window for contracting percentage.

The model assists the District with estimating its available project capacity for PB submission by providing a tool for scenario analysis. Results of the model show the effects of allowing projects to shift in the schedule and adding project work on employee utilization, contractor utilization, and leveling monthly project work. We recommend expanding the model with more detailed resource requirements per project to identify for the Sacramento District where to allocate its scarce resources to achieve the best effects for total project portfolio management.

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CHAPTER 1:

BACKGROUND

1.1 OVERVIEW

The Sacramento District office of the United States Army Corps of Engineers (USACE) manages civil works, environmental, and military projects. Its customers are the Department of Defense, other federal agencies, and regional, state, and local governments and authorities. Each year, it is asked to estimate its capacity for new work in the civil works area. The federal budget process uses this capacity for input into the process. The District does this by estimating its total project management and design capacity and then subtracting the current budgeted project expenditures during the next fiscal year. The annual President's Budget (PB) submission then uses this estimate as an input. The estimate of the available capacity for the next year is complicated by the uncertain demand for its services, especially near the end of the fiscal year (FY) by military commanders for military construction projects. The military commanders pay for these projects out of operation and maintenance (O&M) funds of installations and bases. The commitments for this type of construction projects are typically made based on the funds remaining at the end of the FY.

1.2 USACE ORGANIZATION

1.2.1 Army Corps of Engineers

Overall, approximately 37,000 civilian and 650 military men and women make up the USACE. They work as leaders in engineering and environmental matters with a diverse workforce of biologists, engineers, geologists, hydrologists, natural resource managers and other professionals and specialists (Sacramento 2011).

The USACE states on its website (USACE 2011) that its mission is to "Provide vital public engineering services in peace and war to strengthen our Nation's security, energize the economy, and reduce risks from disasters." To accomplish this mission, the USACE is broken up into nine divisions and each division is divided into two to six districts. In total, there are 45 districts divided up among the various divisions. Figure 1.1 shows how the United States and other parts of the world break into divisions and then districts. In general, the districts follow the watersheds in the area of the country that each district administers for the USACE.



Figure 1.1: Map showing the boundaries of the USACE divisions and districts. From Sacramento (2011).

1.2.2 Sacramento District

The Sacramento District, the sponsor of this thesis, is located in the South Pacific Division (Figure 1.2). “In 1968, the Sacramento District became the second largest in the contiguous United States when territory was transferred from the Los Angeles District. Added were all of Utah, except the southwest corner, Colorado from the Continental Divide west, the southwest corner of Wyoming, northeast corner of Arizona and the northwest corner of New Mexico for a total of 290,000 square miles” (Sacramento 2011). Figure 1.3 shows the Sacramento District boundaries.

The mission statement for the Sacramento District says, “We provide innovative and enduring engineering solutions across the full spectrum of program/project delivery to provide value and quality, on-schedule, to our military/civilian customers and partners and we support our

South Pacific Division Regulatory Boundaries

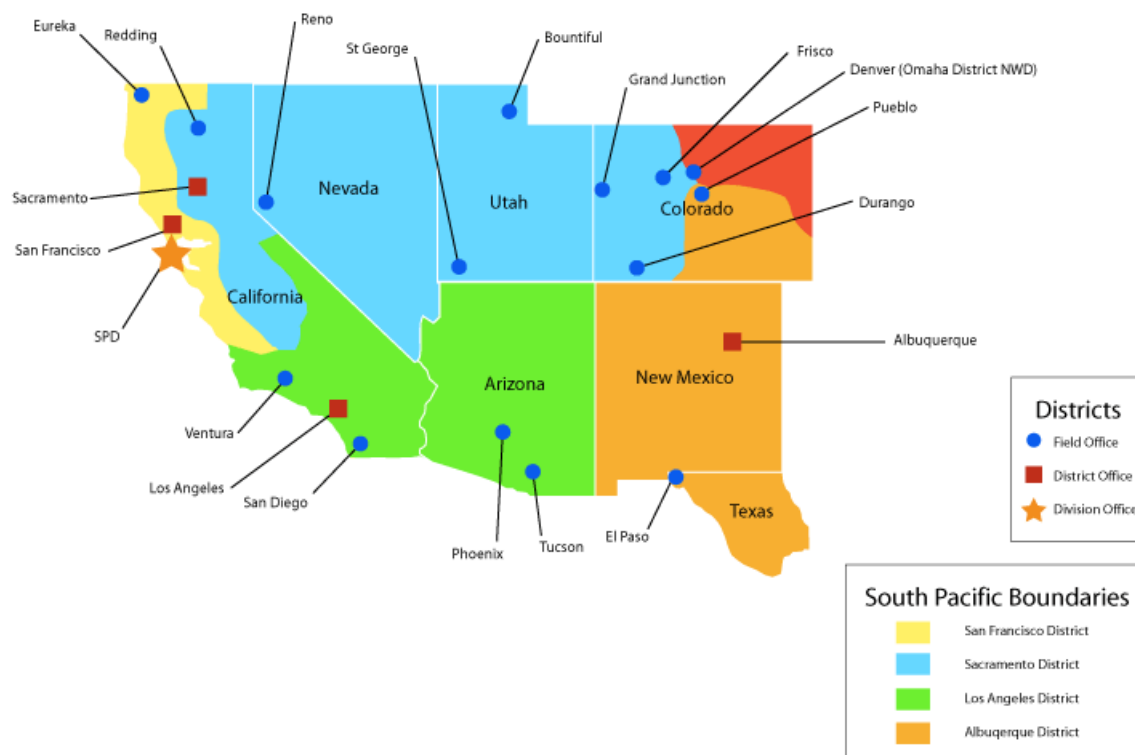


Figure 1.2: Map of South Pacific Division boundaries and location of district offices. The Sacramento District is located in this Division. From Sacramento (2011).

federal/state partners by responding to national emergencies with leadership and technical expertise” (Sacramento 2011).

1.3 PROJECTS

1.3.1 Types

The Sacramento District classifies its projects into three main types. They are: civil works, environmental, and military.

The USACE civil works mission involves works “of a civil nature.” This mission goes back almost to the origins of the United States. Over the years, as the nation’s needs have changed, so have the Army’s civil works missions. The missions currently fall in four broad areas: “water infrastructure, environmental management and restoration, response to natural and man made disasters, and engineering and technical services to the Army, DoD and other Federal agencies” (Sacramento 2011).

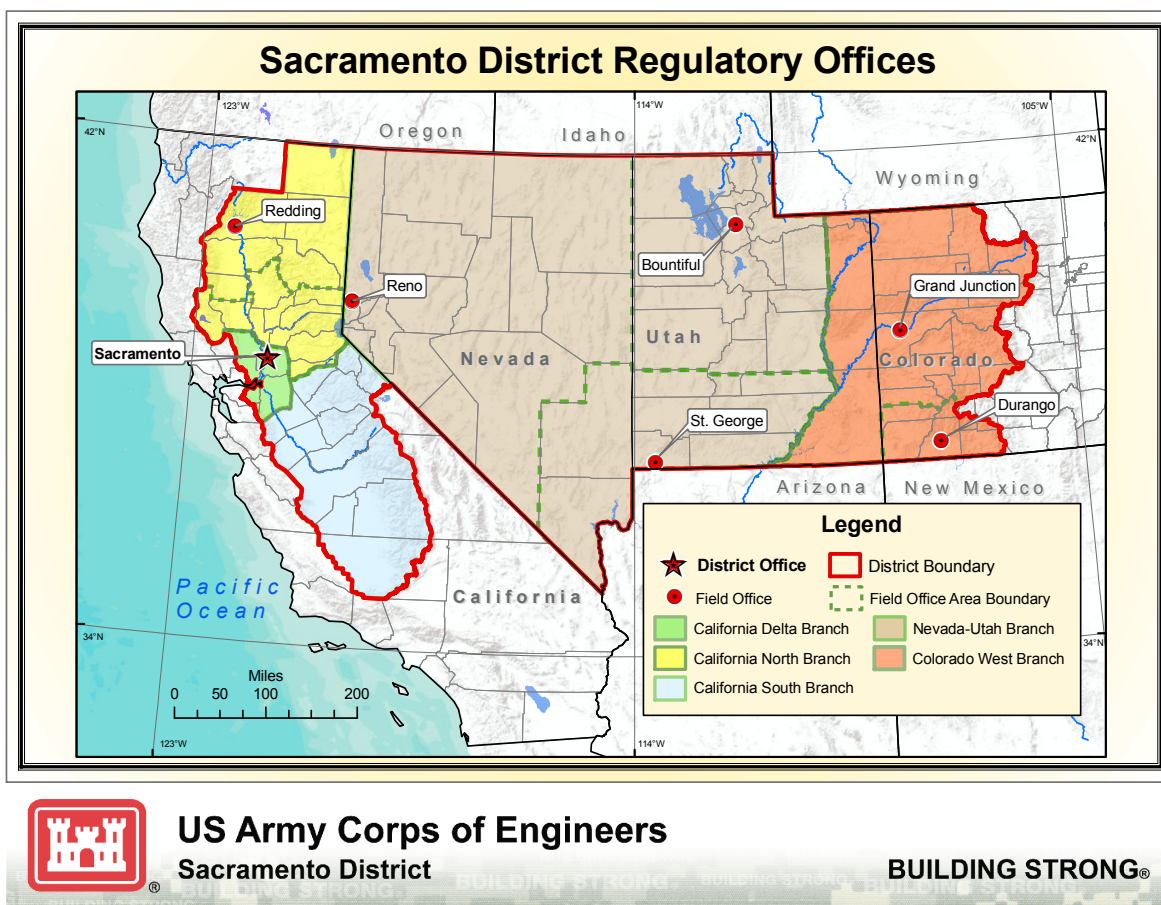


Figure 1.3: Map of Sacramento District boundaries, field offices, and branches. From Sacramento (2011).

The USACE environmental mission supports both military and civil agencies. It serves the United States through management, design, and execution of cleanup and protection activities. It cleans up military sites contaminated with hazardous waste, radioactive waste, or ordnance while complying with federal, state, and local environmental laws. The environmental mission also ensures that all USACE projects, facilities, and associated lands meet environmental standards (Sacramento 2011).

The USACE military mission provides the following services: design, construction, project management, operations, and maintenance for the U.S. Army, the U.S. Air Force and other federal agencies. In addition, the military mission also includes performing environmental clean up for formerly used defense sites and other specified military sites (Sacramento 2011).

1.3.2 Project Size

Civil works projects are usually greater than \$10 million and last 10–15 years. They are conducted in partnership with regional, state and local governments and authorities. At any given time, the District has approximately 60 projects of this type at some point in the project life cycle. In comparison, the majority of military projects are less than \$1 million, and last less than one year from concept through design to contract. In recent years, the District executed 300–400 of these projects annually. Environmental projects and larger military projects span the duration gap between the two previously described civil works projects and small military projects (Nestler 2010).

1.3.3 Project Funding

The District considers the total amount of work it can perform in a year as capacity, which it measures in terms of millions of dollars of project costs. In recent years, the District has executed approximately \$550 million in total projects. Funding for projects performed by the District generally come in two types: directed funding from Congress and projects funded by local military commanders' O&M accounts (Nestler 2010). In the last year, the District received \$120–130 million through the PB process.

Civil works projects, environmental projects, and larger military projects are funded via request by the Army through the PB process or as Congressional inserts to the budget. Due to the long-term nature of these projects, this funding is spread over multiple years and is somewhat flexible. Also, 35%–50% of the funding for civil works projects usually comes from partner organizations, which are usually state and local agencies (Nestler 2010).

In comparison, installation or base commanders' O&M funds often fund smaller military projects. This type of money usually expires at the end of each fiscal year. This means that these projects need to go from concept, through some level of design, to contract within a fiscal year. The number, scope, and timing of these projects varies greatly from one year to the next and during the year. These smaller military projects tend to come to the District's attention later in the FY, once commanders have a better feel for their budget. The District does not want to turn away any of these projects out of concern that it will harm its reputation as the "go to guys" for such projects. Turning down projects could result in less work in the future from those it turned away (Nestler 2010).

The smaller military projects' appearance late in the FY adds to the pressure of completing

them before the end of the FY. Some environmental projects also fit into this category also. If a project shows up later in the FY (i.e., during the last FY quarter, July–September) one way the District accomplishes the project is to do a partial design (e.g., 30%) and then award a “complete the design-build” contract instead of awarding a contract for only the construction itself. The drawback to this technique is that it increases the oversight responsibility for the District design engineers and reduces the amount of time USACE employees spend on actual design work. This also burdens the contracting department with a large amount of work to complete before the end of the FY and may come close to exceeding its contracting capacity (Nestler 2010).

1.3.4 Employees

“Approximately 1,000 military and civilian employees work in the Sacramento District today” (Sacramento 2011). Of the 1,000 employees in the Sacramento District, some only support one of the mission areas described earlier, while others support more than one. Some employees are only involved in the ongoing operation of their facility and should not be considered as a resource available for assignment to new projects. For example, the operator or maintenance employee at a lock or dam should not be included.

1.3.5 Contractors

USACE projects are not done solely by the employees of the Sacramento District office. It increases its project capacity through the outsourcing of functions where demand exceeds capacity. For example, the District contracts some design engineering to engineering design companies. Outsourcing this work, however, requires a certain amount of contract supervision by USACE employees. Note that some activities are inherently governmental. Contracting authority is an example of an activity that cannot be contracted out.

The Sacramento District is concerned that if a USACE design engineer, planner, or other employee is spending the majority of his time supervising contracted design companies, then he may not be maintaining his core competencies in engineering design. The Chief of Engineers has recently expressed concern that the percentage of work contracted out be limited to a level that allows sufficient retention of core competencies. However, there was not an exact level specified; also, this can vary for different specialties (Nestler 2010).

1.3.6 Current Techniques

In order to maintain its reputation as the “go to guys,” the USACE does not want to over commit on the number of projects it can manage at any point in time. The PB process adds to its overall

project load and the Sacramento District wants a tool that can help determine the amount of projects it should request through that process. The tool could also be used over the longer term to help shape the workforce to the types of work it manages.

Currently, the Sacramento District office uses a simple regression analysis of work performed in past years with the total number of employees as the independent variable. It uses this model, based on the number of employees it expects to have on hand, to estimate the amount of available capacity during the next fiscal year. It then provides the result as an input to the annual PB submission. One problem with this approach is that, with recent growth, it is currently extrapolating outside the boundaries of its data. Also, the District believes that this growth trend is unlikely to continue (Nestler 2010).

1.4 SCOPE OF RESEARCH

We develop a project capacity and leveling model for the Sacramento District office. It considers the planned budget for projects over the next year. The model is a mixed integer linear program. We use historical data provided by the Sacramento District from 2009 to 2011 to build and test the model.

The model's objective function maximizes a function that calculates the value of the lowest monthly total amount of project dollars budgeted in all time periods of interest, and subtracts penalties for too little or too much contracting work. The penalties measure the total amount of work contracted as a percentage of the total project budgets in each time period. The decision variables are the number of employees or contractors assigned to each project and the number of months to move earlier or move later project budgets. The constraints are the number of employees and contractors available to contribute work to each project and the number of month available to shift the projects in time.

We developed notional data that explores several possible scenarios, and used the model to analyze each scenario. The notional data explores some possible scenarios to discover how changes to this data and the constraints affect the percentage of utilization of USACE employees and the percentage of total project budget amount contracted. We also explored how these variations affect consistency from one month to another in the total project work.

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CHAPTER 2:

LITERATURE REVIEW

2.1 LITERATURE

Many researchers have conducted research in the area of project management, resource allocation, and scheduling. Li and Womer (2011) provide a survey of the evolution of project scheduling work done over the past 50 years. They also discuss the application of stochastic resource constrained project scheduling to the military. Such military applications are mission planning, path planning for unmanned aerial vehicles, and configuring logistic networks. Figure 2.1 shows a graphical view of the evolution of project scheduling.

Kelley (1961) established the critical path method (CPM) mathematical basis. CPM is for planning, scheduling, and coordinating complex engineering type projects. Usually, this method is applied to a single project without regard to how it affects other projects. The method uses sequence information, durations, and costs for each component of the product. The paper describes the linear program formulation that is solved efficiently by network flow methods. When applied to the USACE, this technique is used to manage each project individually without considering effects on other projects.

As mentioned by Li and Womer (2011), program evaluation and review technique (PERT) was described over 50 years ago by Malcolm et al. (1959). The paper describes the development and application of the technique for controlling project progress. The technique was developed for the Program Evaluation Branch of the Special Projects Office of the Navy. PERT added the uncertainty of the time at which a milestone would be completed into the project management technique. This added a stochastic element to the problem and the solution was then given as a mean and standard deviation of completion time. For larger projects where uncertainty in completing tasks has a big effect on individual projects, this technique could be used to manage individual USACE projects.

Next, graphical evaluation and review technique (GERT) (Moore and Clayton 1976) incorporates probabilistic outcomes and feedback loops. Moore and Taylor (1977) used GERT in an application of multiple research and development projects worked on concurrently and sequentially by multiple research teams. These elements are required for R&D projects due to the uncertain length of project time and outcome of projects. Taylor and Moore (1980) further

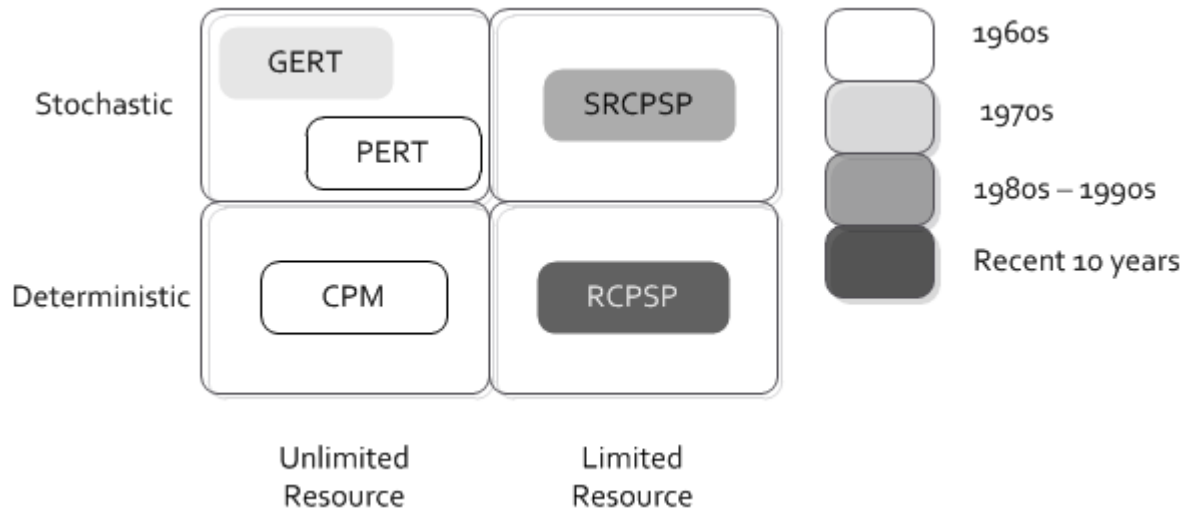


Figure 2.1: Evolution of the research field of project scheduling. Redrawn from Li and Womer (2011).

extended GERT with queueing graphical evaluation and review technique (Q-GERT) to make it more applicable to R&D projects and team. It adds queues for service activities and adds other features applicable to model R&D planning schemes. Since the Sacramento District has a portfolio of projects, with each demanding some of the same resources, these techniques would be useful to manage the large portfolio of projects and its demands on resources.

CPM, PERT, GERT, and Q-GERT all model project management by assuming that resources are unlimited. Herroelen, Reyck, and Demeulemeester (1998) survey the resource constrained project scheduling problem literature available at that time. This problem deals “with the optimal allocation of scarce resources over time” (Herroelen, Reyck, and Demeulemeester 1998). Brucker et al. (1999) propose notation, classification, model, and methods for resource constrained project scheduling and provides a classification scheme, activity characteristics, and objective function for machine scheduling. Patterson (1984) looks at finding the optimal solution through an enumeration of the possible solutions to the problem of resource conflict resolution. This conflict arises when multiple activity demand exceeds the resource available at the time. Bartusch, Mohring, and Radermacher (1988) add resource and time constraints to project networks.

Herroelen and Leus (2005) provide a survey of project scheduling under uncertainty. Projects in the real world have project activities subject to uncertainty which is resolved as the project is executed. Ballestin and Leus (2009) also describe resource constrained project scheduling with stochastic activity duration. The article develops a heuristic to produce high quality solutions to

this problem. Ballestin (2007) discusses “when it is worth the effort, in heuristic algorithms, to work with stochastic duration instead of deterministic ones.”

An important area of concern for businesses is the allocation of human resources for staffing in areas of uncertainty. Bassamboo and Zeevi (2009) describe a data driven solution method to decide the optimal staffing level of a large call center. Gurvich, Luedtke, and Tezcan (2010) also look at staffing a call center with uncertain demand. This uncertain demand is parallel to the problems the Sacramento District faces. The difference is that the demand occurs over a longer time frame than the short term fluctuations in demand observed by a call center.

Hendriks, Voeten, and Kroep (1999) develop a method to allocate human resources in a multiple project R&D environment. They developed two indicators called the project scatter factor and the resource dedication factor. These indicators, when applied, resulted in a simplified resource allocation process and better project and business results. Huemann, Keegan, and Turner (2007) review the prior research of human resources management (HRM) in a project-oriented company. They develop a model for the critical HRM aspects of a project-oriented company and summarize the major shortcomings of current research. These factors are important to the Sacramento District since it is largely a project oriented organization. Implementing these metrics would help allocate and monitor the District’s work force to the many projects it designs and manages.

With all of the research in project planning techniques the question arises asking if it matters to project success. Papke-Shields, Beise, and Quan (2010) research this question and concludes that “the level of use of PM practices is indeed related to project success. Finally, the results suggest that the PM practices that make a difference may not be the most frequently used.” This paper provides support to the use of project management techniques in the Sacramento District Office.

For the companies that have a choice about the projects to add to its project portfolio, Stummer and Heidenberger (2003) “describes a three-phase approach to assist research and development managers in obtaining the most attractive project portfolio.” The first phase is a screening process. Next, a multi-objective integer linear programming model determines the solution space of all efficient portfolios. The final phase finds a “portfolio that fits the decision-maker’s notion.” If the Sacramento District were to decide that it had a choice about which projects to put in its portfolio, this technique would help it decide on the projects to accept.

2.2 SUMMARY

After reviewing this literature, we identified the Sacramento District as having some unique requirements that are not considered in the literature. First, it either wants to or must execute all projects brought to it, so portfolio selection is not a consideration. Next, it also wants to utilize all of the Sacramento District employees but not overburden the employees with overseeing contract work to the point where they can not maintain their core competencies. The stated position is that employee size will not grow in the short term. This means that that the employee resource is constrained both by a desire to keep all employees employed and by the number of current employees. The contractor resource is considered unconstrained by supply but constrained at the lower end by the desire to maintain some contracting with local architectural engineering firms to maintain relationships for future projects and at the upper end by the management burden of overseeing contracts. Finally, the District has uncertainty about the number of new projects, the dollar amount of the project, type, start date and duration of projects. This thesis will take these factors into account in the model.

CHAPTER 3:

MODEL FORMULATION AND DATA

3.1 INTRODUCTION

This chapter presents the Sacramento Allocation Model (SAM) and the data set. Given a list of projects with cost and duration and a list of workforce availability and skills, SAM determines the optimal start times and amount of contracting for each of those projects so as to maximize the value of the lowest total amount budgeted in any month within the time horizon of interest. This has the effect of reducing the variation of the budget total from month to month. Penalties are subtracted for the percentage of the total budget contracted outside the desired window for contracting percentage. Contracting percentage is the total amount of work contracted of the total amount of budgeted project totals in each monthly period.

3.2 SAM MIXED INTEGER PROGRAM

3.2.1 Indices and Sets [approximate cardinality]

$p \in P$	Project in Portfolio (alias i, j, k) [700]
$o \in O$	Employee Occupational Codes [80]
$g \in G$	Employee Grade [4]
$e \in E$	Employee Experience [Binary]
$c \in C$	Contractor full time equivalent (FTE) type [5]
$t \in T$	Time periods [12 months * 2 years = 24]
$f \in F$	Offset of project in months $\{-1,0,1,2,3\}$

3.2.2 Data [units]

$budget_{p,t}$	Budget for project p in time period t [\$]
----------------	--

$e_avail_{o,g,e,t}$	Count of employees of occupational code o , grade g , and experience e available for assignment in time period t [employees]
$e_contrib_{o,g,e}$	Amount of contribution available from a single employee of occupational code o , grade g , and experience e for assignment [\$]
c_avail_c	Count of contractors of type c available for contracting [contractors]
$c_contrib_c$	Amount of contribution available from one FTE contractor of type c [\$]
low_pen	Penalty factor for low contracting [\$]
$high_pen$	Penalty factor for high contracting [\$]
$very_high_pen$	Penalty factor for very high contracting [\$]

3.2.3 Calculated Data [units]

$$budget_shift_{p,t,f} = budget_{p,t-f} \text{ [\$]} \quad \forall t \in T, f \in F$$

3.2.4 Variables [units]

$X_{o,g,e,p,t}$	Count of employees of occupational code o , grade g , and experience e assigned to project p in time period t [employees]
$Y_{c,p,t}$	Count of contractors of type c assigned to project p in time period t [contractors]

$W_{p,f}$	Binary partition variable, 1 if offset f used for project p [binary]
$CONTRACT_p$	Binary partition variable, 1 if project p is contracted [binary]
$SLACK_t$	Slack contracting used for penalty equation in time period t [\$ / \$]
LOW_t	Low contracting used for low contractor utilization per- centage in time period t [\$ / \$]
$HIGH_t$	High contracting used for high utilization in time period t [\$ / \$]
$VHIGH_t$	Very high contracting used for very high contractor utiliza- tion in time period t [\$ / \$]
Z	Least amount of total budget in a single time period of all of the time periods t [\$]

3.2.5 Objective Function

$$\max Z - \sum_t high_pen HIGH_t - \sum_t vhigh_pen VHIGH_t - \sum_t low_pen LOW_t \quad (3.1)$$

3.2.6 Constraints

$$\sum_p X_{o,g,e,p,t} \leq e_avail_{o,g,e,t} \quad \forall o \in O, g \in G, e \in E, t \in T \quad (3.2)$$

$$\sum_p Y_{c,p,t} \leq c_avail_{c,t} \quad \forall t \in T \quad (3.3)$$

$$\begin{aligned}
& \sum_{o,g,e} X_{o,g,e,p,t} * e_contrib_{o,g,e} + \sum_c Y_{c,p,t} * c_contrib_c \\
& \geq \sum_f budget_shift_{p,t,f} * W_{p,f} \quad \forall p \in P, t \in T
\end{aligned} \tag{3.4}$$

$$\sum_f W_{p,f} = 1 \quad \forall p \in P \tag{3.5}$$

$$\frac{\sum_{c,p} Y_{c,p,t} * c_contrib_c}{\sum_p budget_{p,t}} - SLACK_t - HIGH_t - VHIGH_t + LOW_t = 0.10 \quad \forall t \in T \tag{3.6}$$

$$\sum_{o,g,e,t} X_{o,g,e,p,t} * e_contrib_{o,g,e} \leq \sum_t (1 - CONTRACT_p) * budget_{p,t} \quad \forall p \in P \tag{3.7}$$

$$\sum_{c,t} Y_{c,p,t} * c_contrib_c \leq \sum_t CONTRACT_p * budget_{p,t} \quad \forall p \in P \tag{3.8}$$

$$Z \leq \sum_{p,f} budget_shift_{p,t,f} * W_{p,f} \quad \forall t \in T \tag{3.9}$$

$$0 \leq SLACK_t \leq 0.25 \quad \forall t \in T \tag{3.10}$$

$$0 \leq LOW_t \leq 0.10 \quad \forall t \in T \tag{3.11}$$

$$0 \leq HIGH_t \leq 0.35 \quad \forall t \in T \tag{3.12}$$

$$0 \leq VHIGH_t \leq 0.30 \quad \forall t \in T \quad (3.13)$$

$$0 \leq X_{o,g,e,p,t} \quad \forall o \in O, g \in G, e \in E, p \in P, t \in T \quad (3.14)$$

$$0 \leq Y_{c,p,t} \quad \forall c \in C, p \in P, t \in T \quad (3.15)$$

$$W_{p,f} \in \{0, 1\} \quad \forall p \in P, f \in F \quad (3.16)$$

$$CONTRACT_P \in \{0, 1\} \quad \forall p \in P \quad (3.17)$$

3.2.7 Discussion of Objective and Constraints

Objective:

- (3.1) The objective function maximizes the value of the lowest total amount budgeted in any month within the time horizon of interest minus penalties for the percentage of the total budget contracted outside the desired window for contracting percentage.

Constraints:

- (3.2) Assign no more than the total count of employees of each occupational code, skill level, and experience level available in each time period t to the projects.
- (3.3) Constraint to assign no more than the count of contractors available.

- (3.4) Allocates the resources, represented by dollar amounts, from employee and contractor resources to meet the budget requirements.
- (3.5) With constraint 3.4, chooses the optimal number of months to move each project to maximize the objective function.
- (3.6) Constraint to allocate penalties based on the amount of contracting that the District does with outside companies. This constraint in combination with the objective function wants some contracting but add penalties as contracting percentages increases. Figure 3.1 shows the penalty function.
- (3.7) If project is not contracted assign the project budget to USACE employees.
- (3.8) If project is contracted assign the project budget to contractors.
- (3.9) Set Z so that it is equal to or less than all monthly total budget amounts in each of the monthly time periods. Because Z is maximized by the objective function, Z will equal the minimum of total budget amounts for all monthly time periods.
- (3.10) Allocate no penalty for contracting percentage from 10–35%.
- (3.11) Allocate light penalty for low contracting percentage from 0–10%.
- (3.12) Allocate moderate penalty for high contracting percentage from 35–70%.
- (3.13) Allocate more severe penalty for very high contracting percentage from 70–100%.
- (3.14) Non-negative constraint.
- (3.15) Non-negative constraint.

(3.16) Binary constraint.

(3.17) Binary constraint.

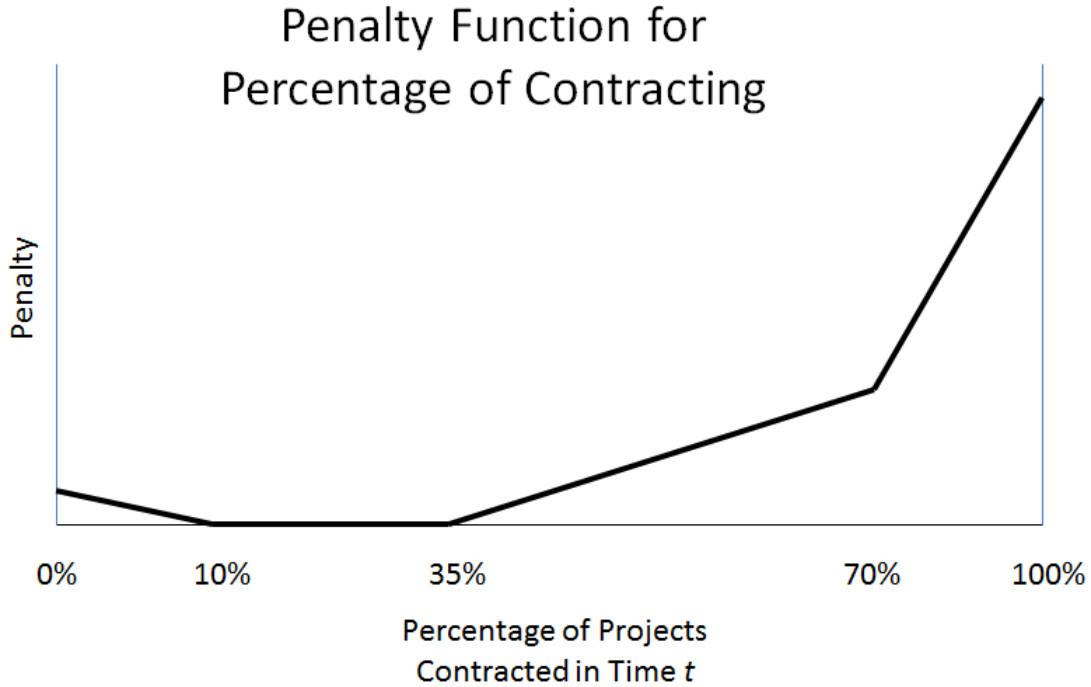


Figure 3.1: Graph of the penalty function implemented in SAM for different level of contracting percentages. Figure not drawn to scale.

3.3 DATA

The Sacramento District office provided the data for analysis in Microsoft Excel files and was the result of database queries from Project Management Information System (P2). This is the project management database system USACE uses to facilitate project planning, execution, and management (ERDC 2010). The files are as follows: a table of contribution of employees to projects, a table of employee characteristics, and a table of project budgets. The tables are in two versions; one has the data summarized by year, and the other breaks the data into monthly increments.

The first table of data contains the contribution in dollar amounts to project accounts by employee numbers broken into fiscal years and month. The table has over 96,000 entries and consists of data from 2009, 2010, and six months of 2011. Based on this data, it appears that the average employee contribution to projects is \$107,600 per year or about \$9,000 per month. Statistical analysis gave a median of \$102,055, a range from \$150 to \$322,364, and a standard

deviation of \$73,410. This data is defined as the amount that was directly charged to a specific project account and the amount is the fully burdened cost of the employee for the amount charged to the project account.

Figure 3.2 is a plot of the total amount of employee contribution to all projects broken into months and FYs. The graph shows that the amount of Sacramento employee contribution to projects in dollar terms has grown in 2010 and 2011. It also shows that employee contribution to total project amounts varies from month to month. It is not a constant amount.

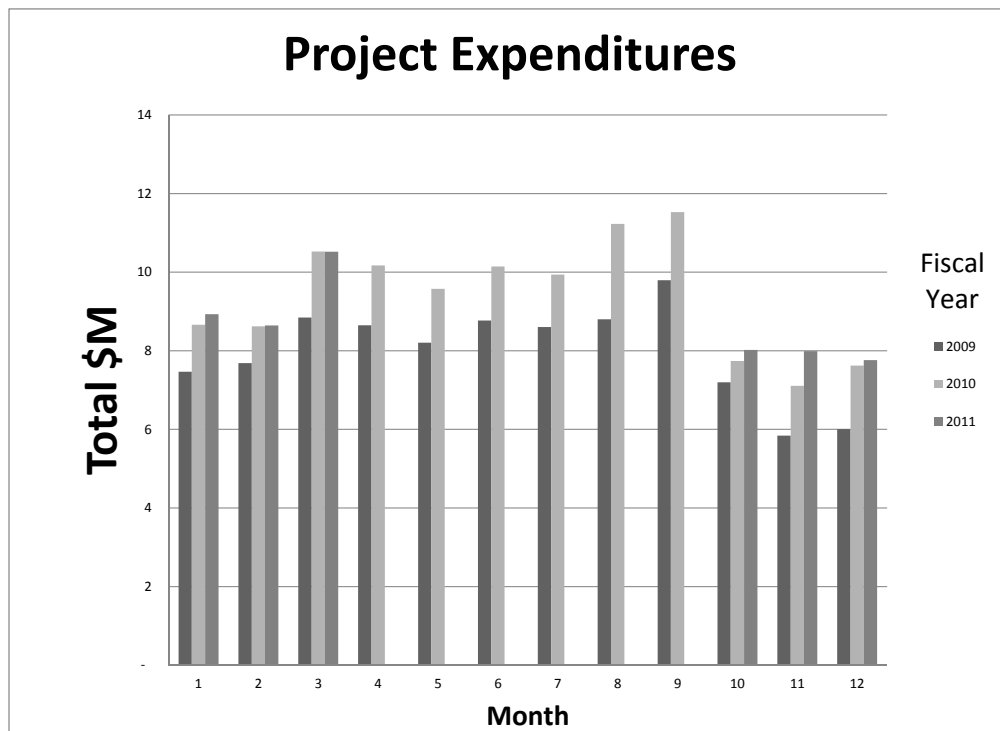


Figure 3.2: Graph of the actual project employee contribution by fiscal year and month.

There are two interesting points in the graph. The first is a steep drop of about 30% from month 9 to month 10. These months are September and October, respectively. This time is the end of one FY and the start of the next in the federal budget process. The United States federal budget for FY XX runs from October of year (XX-1) to September of year XX. Based on information from the Sacramento District, one of the causes of this large drop is the FY end of year push to get enough work done on a project so that the O&M funds are obligated from commanders

funding military construction projects. At the end of the FY, any money not spent would be lost, but once the funds are obligated the commander will not lose the funding from the federal budget.

The other interesting point is months 2 and 3, which are February and March, respectively. During this time there is a rise of about 25%. One possible cause is that, over the past couple of years, Congress has not passed the budget in time to start in October. Continuing resolutions are used to keep the federal government running. With a continuing resolution, the federal budget is kept at the previous year's funding level and new projects are not funded. Therefore, when a budget is finally passed, the new spending level causes the project expenditures to rise.

The second table of data contains data from fiscal years 2009, 2010, and 2011 of employment numbers. It identifies all of the occupational codes and grades with indicators for less than two year's experience military and civil works project experience. It has a total of 3,379 entries.

Table 3.1 summarizes the occupational code data. This table illustrates the growth and leveling off of the number of employees in the Sacramento District.

Table 3.2 shows the level of experience of the employees. Experience is defined as an employee who has greater than two years of time working at the Sacramento District. The total employee numbers are different from those shown in table 3.1 due to blanks in the table for experience.

Table 3.3 shows a summary of the employee grades. In 2009, most of the employees were under the National Security Personnel System. In 2010 and 2011, personnel were transitioned out of that system and back into the General Service pay system. The two systems have different scales for grade, and the table reflects those differences.

The last table contains project data by project number identification. Each line consists of the project type, project name, project start and end date, fiscal year, month, budget amount, and expenditure amount. The table contains over 12,500 entries and has entries for the fiscal years 2010 to 2016. This budget amount includes everything related to that project, labor, nonlabor, contracts, etc.

The fiscal year 2010 entries are a roll-up of 2010 and prior years for that project. The budgeted amounts in a month per project has a mean of \$371,000, median of \$19,458, and standard deviation of \$2,350,663. This illustrates the large variation in costs of projects managed by the Sacramento District.

Code	2009	2010	2011	Code	2009	2010	2011
0018	4	7	7	0807	7	7	7
0019		1	1	0808	7	8	12
0023	1	1	1	0809	22	30	37
0025	46	45	36	0810	178	211	237
0028	1			0817	6	6	5
0080	1	1	2	0819	15	17	19
0099	6	5	3	0830	12	15	16
0101	10	11	10	0850	8	15	17
0110	7	8	7	0855	4	3	3
0150	5	8	6	0856	1	1	1
0193	3	3	3	0899	15	15	14
0199	3	2	2	0904			1
0260	4	3	3	0905	9	12	8
0301	23	27	27	0950	1	1	1
0303	54	62	52	0986	2	1	2
0318	15	13	8	1008	2	3	2
0326	29	35	37	1035	11	13	11
0340	10	10	10	1087	1	1	1
0341	10	9	10	1101	5	13	14
0342	4	4	4	1102	41	44	43
0343	6	7	7	1105	4	2	1
0344	1			1106	7	10	9
0361			1	1170	28	43	43
0399	2	4	3	1171	3	2	2
0401	105	108	98	1199	1	4	3
0408	3	3	3	1301	11	10	12
0415	3	3	3	1311	2	2	1
0482	1	2	2	1315	10	9	9
0499	10	10	9	1316	2	2	2
0501	1	1	1	1320	7	8	7
0505	1	1	1	1350	20	23	22
0510	8	7	7	1370	1	1	1
0544	1	2	2	1371	3	4	3
0560	39	36	36	1399	2	2	2
0561	2	3	3	1411	1	1	1
0599		1	1	2210	1	1	1
0690	2	2	1	3502	20	21	16
0699			1	4749	46	53	51
0801	48	48	42	5703	1	1	1
0802	45	40	40	5716	2	1	1
0803	1	1	1	(blank)	24	24	2
0806	1	1	1	Total	1059	1175	1133

Table 3.1: Summary of employee occupational code data. For example, in 2009 there were 10 employees in category code "0101."

Experience	FY		
	2009	2010	2011
No	267	382	351
Yes	638	676	729
Total	905	1058	1080

Table 3.2: Summary of employee experience data. “No” indicates employees with less than two years experience at the Sacramento District. “Yes” indicates more than two years experience. For example, in FY 2010 there were 382 employees with less than two years experience at the Sacramento District office.

Grade	FY		
	2009	2010	2011
01	273	18	6
02	670	55	18
03	66	37	24
04		50	50
05	13	56	48
06		51	50
07		61	55
08	30	36	33
09	4	123	114
10	2	6	8
11		218	237
12	1	309	331
13		125	129
14		20	21
15		9	7
(blank)		1	2
Total	1059	1175	1133

Table 3.3: Summary of employee grade data. For example, in 2010 there were 55 employees in grade “02.” In 2009, most employees were under the National Security Personnel System. In 2010 and 2011, personnel were transitioned back into the General Service pay system.

In FY 2011 civil works projects, the budgeted amounts in a month per project have a mean of \$184,900, median of \$36,250, and standard deviation of \$490,600. Environmental projects have a mean of \$83,760, median of \$9,300, and a standard deviation of \$316,100. Military projects had a mean of \$227,900, median of \$26,100, and a standard deviation of \$1,061,500.

Figure 3.3 shows the graph of budget expenditures planned for FY 2011, and Figure 3.4 shows similar information for FY 2012. FY 2012 budgets are lower than FY 2011 because FY 2012 are budget estimates that are put in P2 to forecast future workload. The District refines the projects when initiated as a result of receiving funding. If all projected and current projects are

accurately reflected in the data, the gap from FY 2011 to FY 2012 reflects the amount of spare capacity the District currently has to take on new projects in the future.

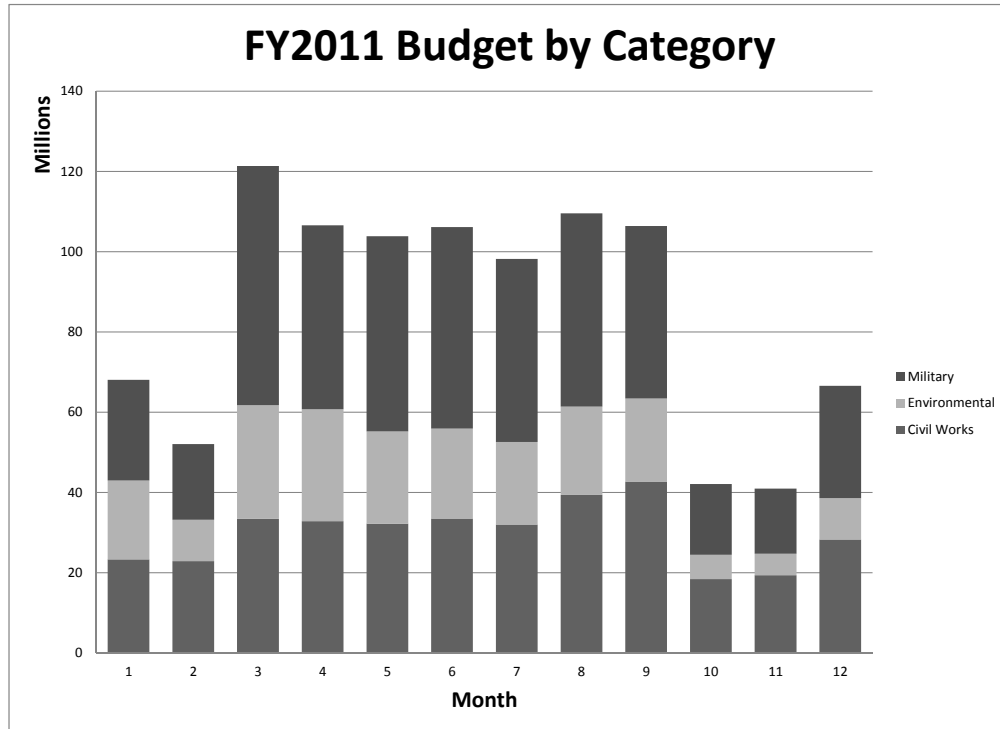


Figure 3.3: Graph of the budgeted expenditures by month for fiscal year 2011.

These graphs show that all categories of projects have fluctuations in the amount budgeted throughout the year. Military projects are projected to grow relatively large during the next year. Environmental projects also has that characteristic.

We requested historical data in a more detailed format for contracted work but the data was not available in time for inclusion in this thesis work. To deal with the lack of data, the next section discusses the limitations and assumptions for the data input to the model.

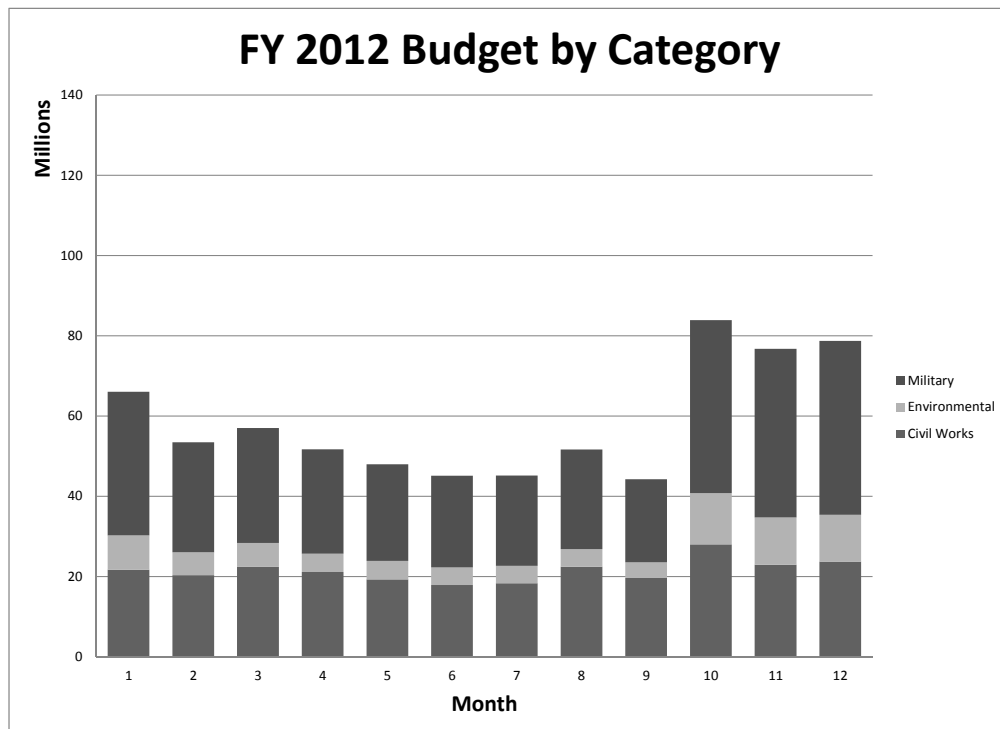


Figure 3.4: Graph of the budgeted expenditures by month for fiscal year 2012.

3.4 LIMITATIONS AND ASSUMPTIONS

We identified limitations in the data during the development of the model. When identified, we made assumptions to either generate notional data or account for the limitation in the model.

The first limitation is that budget amounts in projects are not broken into resource requirements such as design time, planning time, contracting, and construction. If this level of detail was available, more specific resources could be allocated to each project. We overcome this limitation by aggregating the model and data at a higher level so that all employee work costs the same, any employee can perform work to a budget amount, and either a contractor or a USACE employee can perform the work. The last assumption violates the constraints that some project work is inherently governmental. With the penalty piece of the objective function, SAM assigns sufficient work to the District that more than cover for the inherently governmental work.

The next limitation is that historical contracting details for either design or construction was not available for analysis. The lack of this data means that no analysis of historical percentage of the amount of construction or design costs for project could be completed. Historical percentages could be used to make estimates to break projects into these components.

We made the assumption that a project could be moved earlier 1–2 months or later 0–4 months. This assumption shows the effect of how a project management tool levels work over the time horizon of interest.

Finally, we made the assumption a project is either contracted in total or completed by Sacramento District employees in total. This prevents SAM from assigning work for a project in one month to a contract and then the next month assigning it to employees. Once again, the last assumption violates the constraint that some project work is inherently governmental, but it keeps consistency in a project. In the future, this is data input to the model that allows the District to choose certain projects to assign to employees or assign to contractors.

With the above assumptions, we completed SAM and tested it with notional data. The next chapter summarizes the results of running SAM with various inputs.

CHAPTER 4:

IMPLEMENTATION AND RESULTS

4.1 SAM COMPUTATIONAL EXPERIENCE

We implemented trial runs of SAM in the General Algebraic Modeling System (GAMS) (GAMS 2010) using the XPRESS solver. SAM ran on an Intel Core 2 Duo CPU at 1.80 GHz with 4 GB of RAM. The model runs in one to six hours, depending on the range of project movement allowed. This run time is acceptable since this is a tool for project planning; it is not a model that runs everyday. The Sacramento District uses SAM for the PB process estimate and then uses it about every quarter to update the managers on project planning and to start estimating a number for the next PB. The model runs to a relative optimality tolerance of 1%.

4.2 ANALYSIS OF MODEL OUTPUT

First, we ran SAM to show the effects of allowing projects to move earlier or later in the schedule. Figure 4.1 shows graphically the effect of allowing this movement in the schedule. Initially, SAM ran without allowing any movement in budget months. Then it ran at Level(-1, +3) and Level(-2, +4). This means that projects were allowed movement earlier in the schedule by 1 month and later by 3 months and earlier in the schedule by 2 months and later by 4 months, respectively. Table 4.1 contains the data to construct the graph. In the initial case, the monthly budgets range from \$43.7M to \$112.4M, with Level (-1, +3) the budget range drops to \$63.7M to \$109.7M, and with Level (-2, +4) the budgets range drops further to \$63.1M to \$92.4M

The objective function maximizes the value of the lowest total amount budgeted in any month within the time horizon of interest. This has the effect of reducing the variation from month to month. This maximizing effect and variation reduction is balanced with the penalties subtracted for the percentage of the total budget contracted outside the desired window for contracting percentage.

As expected, the project movement effect is the greatest when projects are allowed to move up 2 months earlier in the schedule and back in the schedule up to 4 months. Allowing projects the flexibility to move in the schedule has the effect of lowering the peaks and raising the valleys in the monthly work budget. It also has the effect of maintaining a consistent allocation of work between employees and contractors.

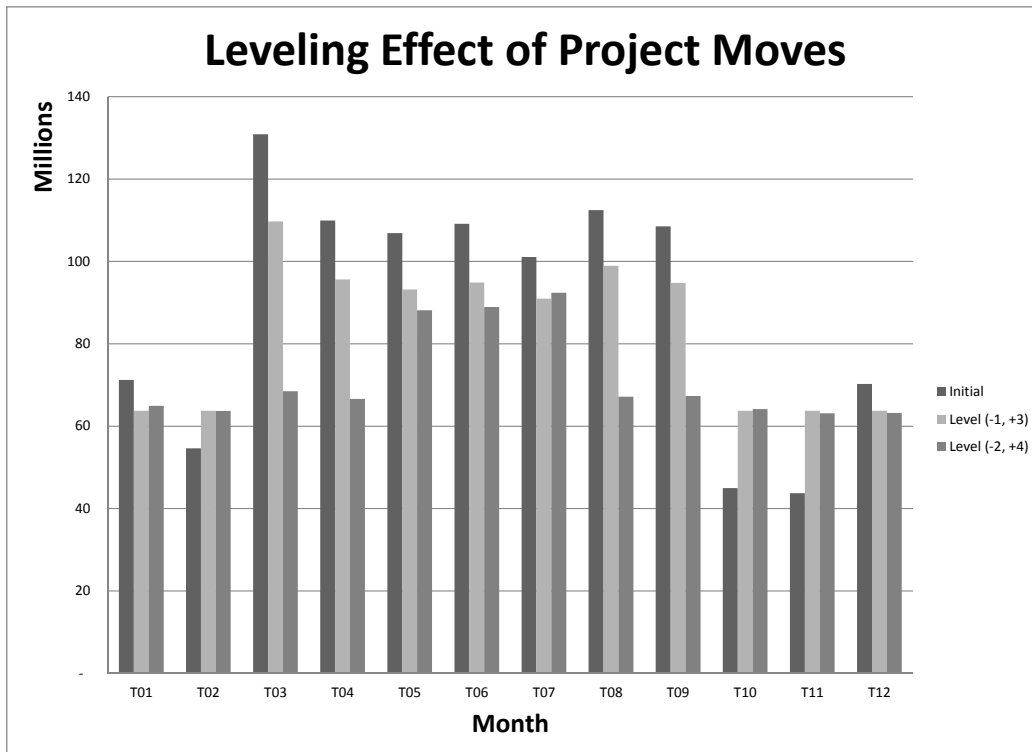


Figure 4.1: Graph of the effect of moving project budgets forward or back in time in FY 2011. Initial is the budgets without any movements. Level(-1, +3) and Level(-2, +4) means allowing movement earlier in the schedule by 1 and later by 3 months and moving earlier in the schedule by 2 months and later by 4 months respectively.

Table 4.2 shows the percentage of the projects that were moved by each of the possible number of months. Relatively high percentages at each end of the movement window shows that more smoothing could be gained by allowing a wider window of project moves.

We developed three measures of effectiveness (MOE) to gauge the effects of adding additional project amounts and at the same time allowing project moves. The added project amount represents the amount the Sacramento District is proposing to request through the PB process. MOE 1 (Project Peak) is the percentage increase from the minimum monthly total budget amounts to the maximum monthly total budget amount over the time horizon. A lower value of this percentage is better than a higher value. MOE 2 (Contracting) is the minimum and maximum monthly percentage of contracting over the time horizon. Ideally, this value would be in the target window for contracting percentage. Percentage of contracting is defined as the percentage

Total Monthly Project Budgets
With Various Levels of Project Movement

Month	Initial	Level (-1, +3)	Level (-2, +4)
T01	\$71,226,882	\$63,754,438	\$64,950,937
T02	\$54,631,489	\$63,753,933	\$63,719,315
T03	\$130,899,540	\$109,715,425	\$68,480,229
T04	\$109,927,583	\$95,625,962	\$66,634,053
T05	\$106,865,985	\$93,205,623	\$88,130,448
T06	\$109,160,429	\$94,864,485	\$88,951,574
T07	\$101,079,951	\$90,965,269	\$92,384,075
T08	\$112,448,912	\$98,950,989	\$67,160,820
T09	\$108,499,361	\$94,789,985	\$67,345,831
T10	\$44,986,582	\$63,739,065	\$64,162,772
T11	\$43,748,218	\$63,734,776	\$63,113,236
T12	\$70,265,242	\$63,766,786	\$63,237,815

Table 4.1: Table of the effect of moving project budgets forward or back in time in FY 2011. Initial is the budgets without any movements. Level(-1, +3) and Level(-2, +4) means allowing movement earlier in the schedule by 1 and later by 3 months and moving earlier in the schedule by 2 months and later by 4 months respectively. For example, allowing project movement Level(-1, +3) in month T02, the total of project budgets in that month is \$63.8M after applying the model's optimization work.

Multiple Runs of SAM

Months Moved	-2	-1	0	+1	+2	+3	+4
Level(-1,+3)	-	41%	18%	8%	8%	26%	-
Level(-2,+4)	36%	10%	8%	4%	3%	13%	26%

Table 4.2: Table of the effect of moving project budgets in time and how much earlier or later projects were moved. Numbers are the percentage of projects moved that number of months to obtain the optimal objective function. Data used was FY 2011 budgeted spending.

of total project budget assigned to a contractor. MOE 3 (Employees) is the minimum utilization of employees throughout the time horizon. Employee utilization is defined as the percentage of available employees assigned to projects. A higher value is better for this MOE so that employees are fully utilized in the project portfolio.

Table 4.3 shows SAM runs and the resulting MOE values. SAM ran at the baseline level and with an additional monthly project amounts of \$6M and \$15M added to the baseline project amounts. We chose these amounts because last year the PB process provided \$120–130 million for the year. This equals a monthly amount of about \$10 million. We used the same levels of project movement windows as defined in Figure 4.1 during the model runs.

The table shows effect of adding project amounts to the baseline in the two columns on the right. The percentages show the range of contracting percentage and the minimum employee

Multiple Runs of SAM				
	MOE	Baseline	Add \$6M	Add \$15M
Initial	1 (Project Peak)	200%	175%	149%
	2 (Contracting)	59–87%	60–86%	69–86%
	3 (Employees)	83%	98%	84%
Level(-1,+3)	1 (Project Peak)	72%	67%	55%
	2 (Contracting)	69–80%	71–83%	77–86%
	3 (Employees)	96%	94%	83%
Level(-2,+4)	1 (Project Peak)	46%	81%	29%
	2 (Contracting)	68–80%	73–85%	75–83%
	3 (Employees)	78%	82%	76%

Table 4.3: Table of the effect of moving project budgets forward or back in time and adding project dollar amounts to FY 2011 budgeted spending. MOE 1 (Project Peak) is the percentage increase from the minimum monthly total budget amounts to the maximum monthly total budget amount over the time horizon. MOE 2 (Contracting) is the minimum and maximum monthly percentage of contracting over the time horizon. MOE 3 (Employees) is the minimum utilization of employees throughout the time horizon.

utilization percentage required to achieve the budget amounts. Because the number of employees were fixed at current levels the percentage of contracting goes up to accommodate the extra project amount added to the total budget. Adding to the project amount has the general effect of lowering the percentage of MOE 1 (Project Peak) due to the fact that adding project amounts increased the denominator of the percentage calculation. This is acceptable because it does provide a more consistent amount from month to month, but the best and most effective way to reduce the variation is by allowing projects moves in the schedule.

With the objective function penalties for high and very high contracting amounts, SAM always maintains MOE 3 (Employees) at high employee utilization. Looking at Table 4.3, the lowest amount of employee utilization was 76%.

4.3 MODEL CONTRIBUTION

The development of SAM shows how effective moving projects is in leveling out total work budgeted from month to month. This benefits the District by keeping work consistent throughout the year. This then benefits employees and contractors by keeping the amount of work consistent from month to month despite the uncertainty in demand for military projects. Also, with the ability to change the number of employees available per month, SAM tailors work allocation to the projected number of employees in each future month.

The inclusion of a penalty function allows the District to set a target level of contracting percentage without setting fixed constraints on contractor or employee utilization that can not be

violated. This allows the model to remain feasible while finding the optimal solution that targets the desired contracting percentage. The target contracting percentage then meets the objective of maintaining a high employee utilization number while allocating some work to contractors. SAM does this while taking into account the unique requirements of the Sacramento District of a fixed employee level. It also allows unconstrained level of contracting by allowing up to 100% contracting. The penalty in the objective function then determines the optimal level of contracting.

The model allows the Sacramento District to explore various scenarios of adding projects to its portfolio and varying employee levels. The scenarios are generated and run to determine how it affects the amount of employee utilization and contracting and the consistency of project work from month to month. Using this information, it makes an informed decision about the budget number requested through the PB process and future employment levels.

SAM provides the initial framework to model portfolio project management at the Sacramento District. Once additional project details become available, the information is easily added to the model. As the District identifies additional constraints, they are added to SAM.

4.4 FUTURE RESEARCH

Further research should first focus on getting additional data for each project. Resource requirements per project is the next step. The data for further analysis and implementation in the model is the identification of resources required for projects. For example, breaking out the budget into costs for design, contracting, planning, and construction allows the identification of the resources that are constraints while allowing for optimal allocation to each project. This then identifies to the Sacramento District where to allocate its scarce resources to achieve the best effects for total project management.

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